Techniques for Measuring Surface Potentials in Space

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Introduction

This presentation summarizes the two primary methods used for measuring surface potentials of bodies in space with examples of applications from space science and space technology programs

Knowledge of surface potential on objects in space is required for:

- Computation of plasma moments
- Ambient plasma density derived from spacecraft potential
- Spacecraft active potential control
  - Science measurements of low energy plasma
  - Electrostatic discharge threat mitigation
- Investigating fundamental physics of spacecraft charging
- Plasma interactions with solar arrays, tethers, electric thrusters, and other electrical space power and propulsion systems
- Fundamental surface charging physics of planetary bodies

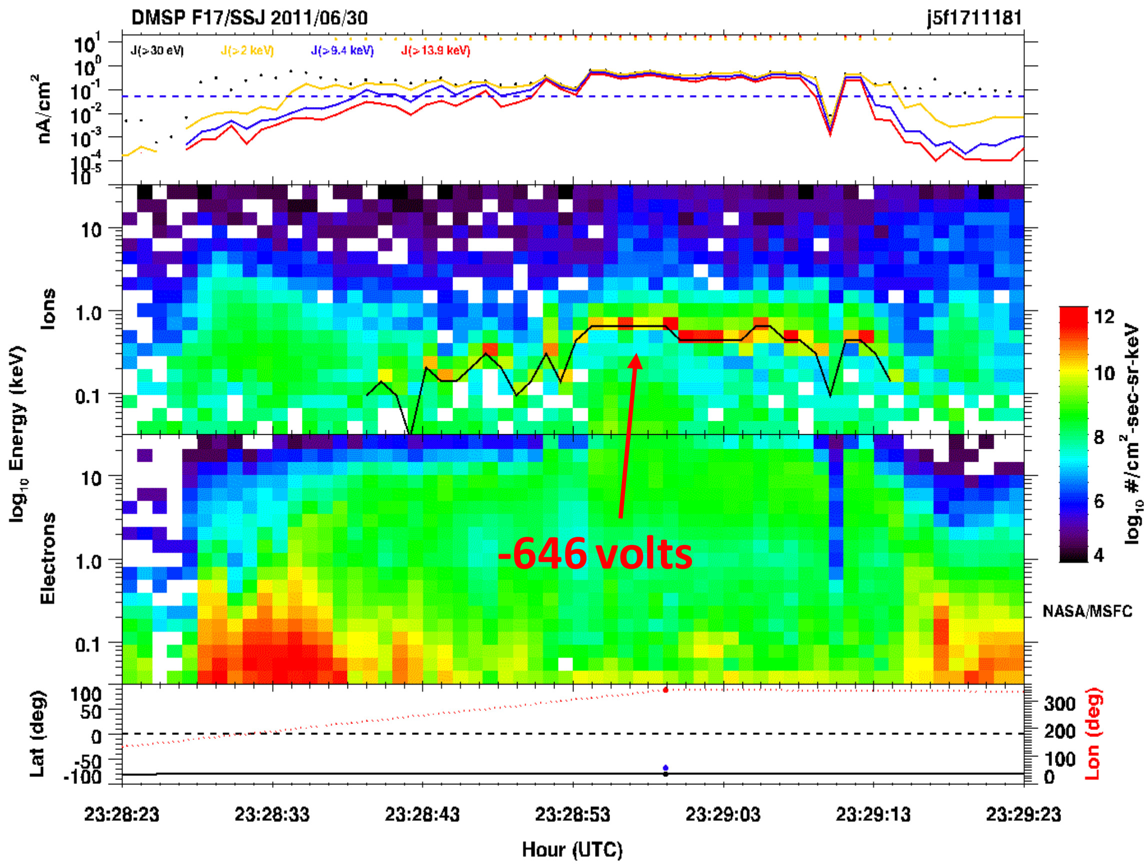
"Ion Line" Charging Signature, $\phi_{s/c} < 0$

- Low energy background ions accelerated by spacecraft potential show up as sharp "line" of high ion flux in single channel

$$E = E_0 + q\Phi$$

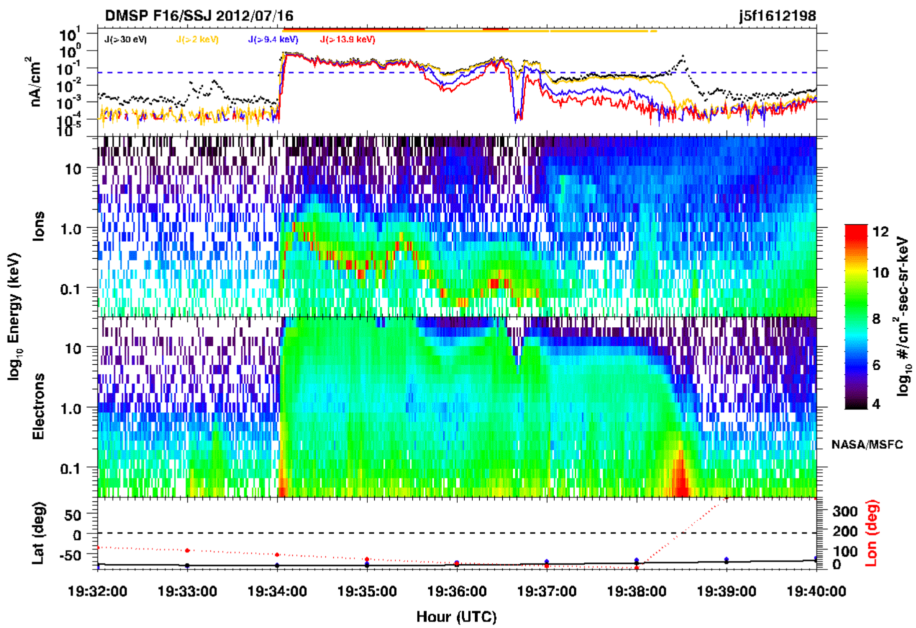
- Assume initial energy $E_0 \sim 0$ with single charge ions (O^+, H^+) and read potential (volts) directly from ion line energy (eV)

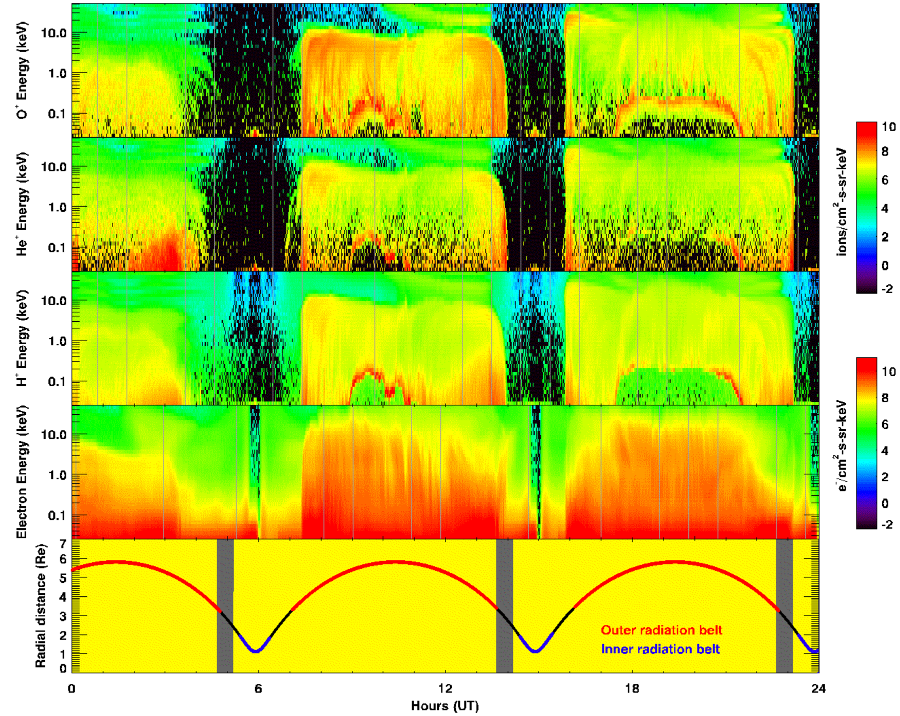
- Accuracy of potential measurement set by energy width and separation of the energy channels used to infer the potential

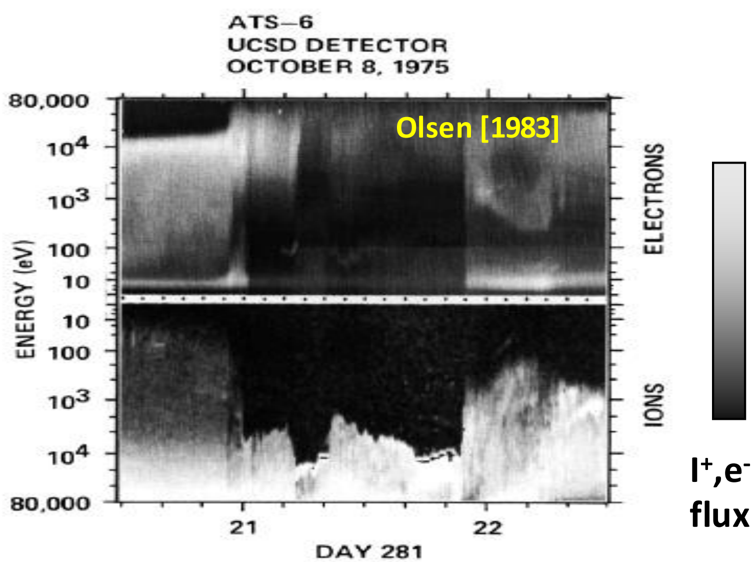


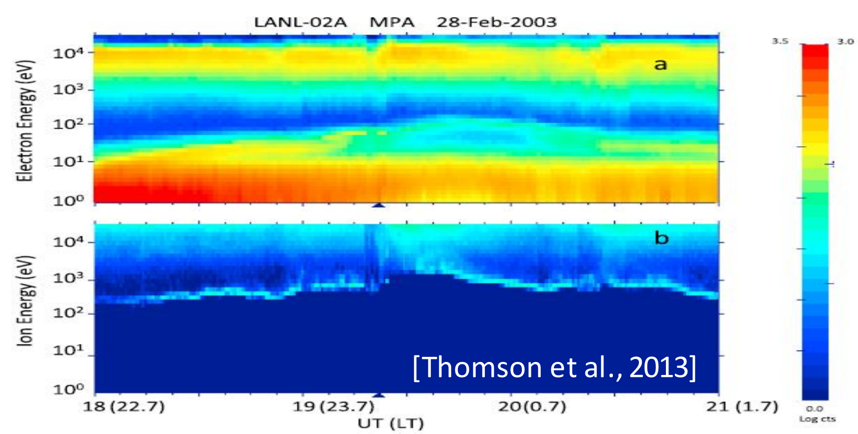
Ion Line Charging Examples

[Parker and Minow, 2014]









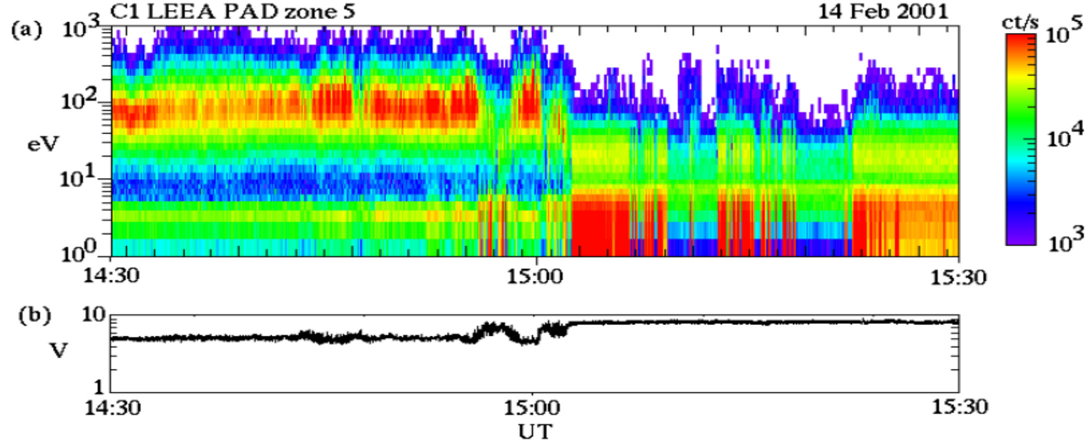
Photoelectron Signature, $\phi_{s/c} > 0$

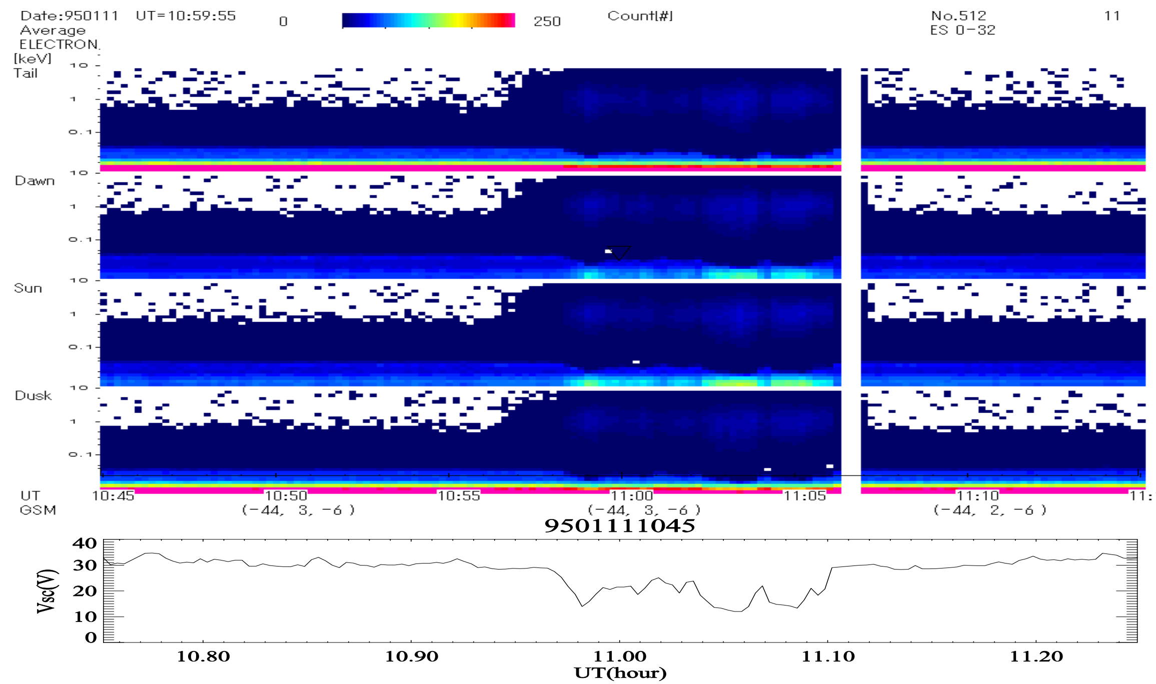
- Spacecraft photoelectrons with energy $E > |q\Phi_{s/c}|$ can escape the spacecraft potential, lower energy electrons are trapped

- Maximum energy of low energy photoelectron population provides record of spacecraft potential when $\phi_{s/c} > 0$ V

- Best in low density plasma environment where photoemission current dominates the plasma currents

[*Szita et al.*, 2001]

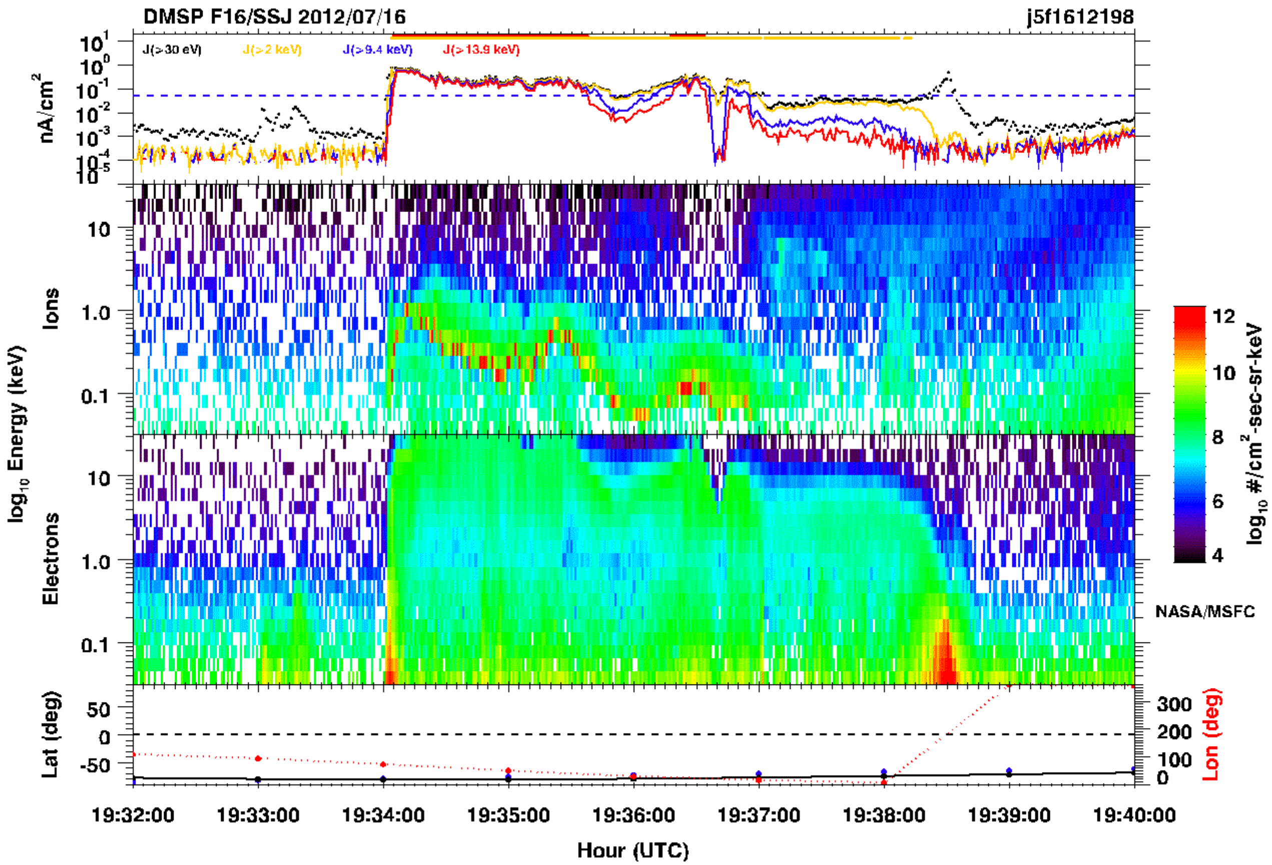




[Shimoda et al., 9th SCTC]

Charging Time History

- Spacecraft potential time series extracted from ion flux records are useful for characterizing spacecraft charging, environments responsible for charging



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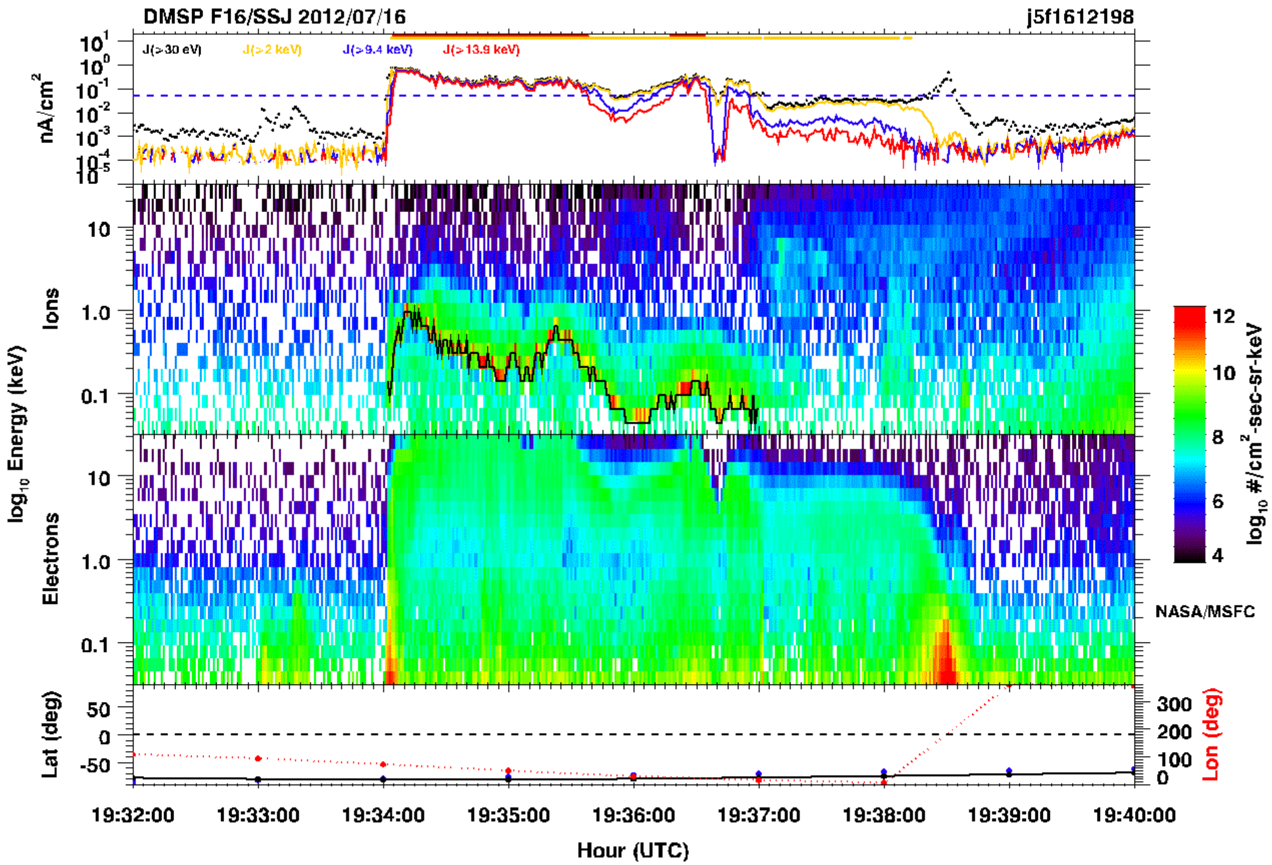

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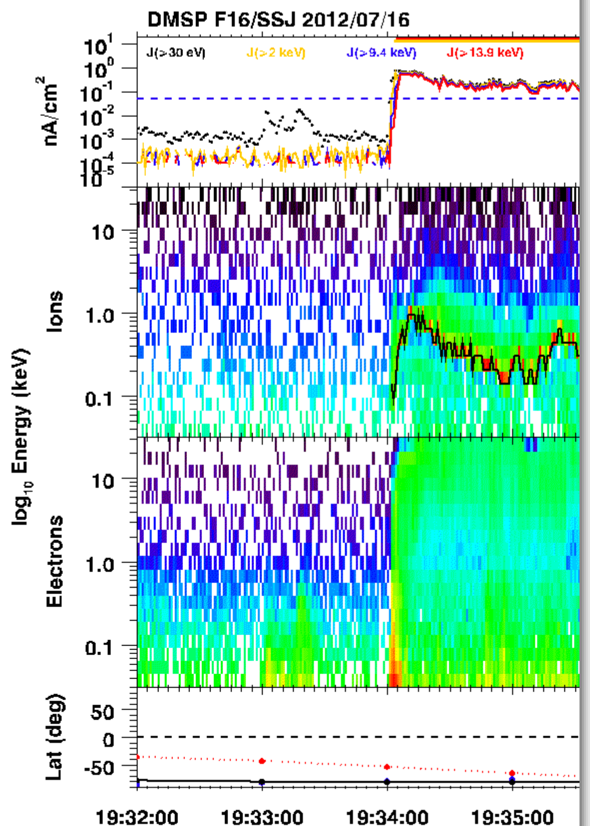
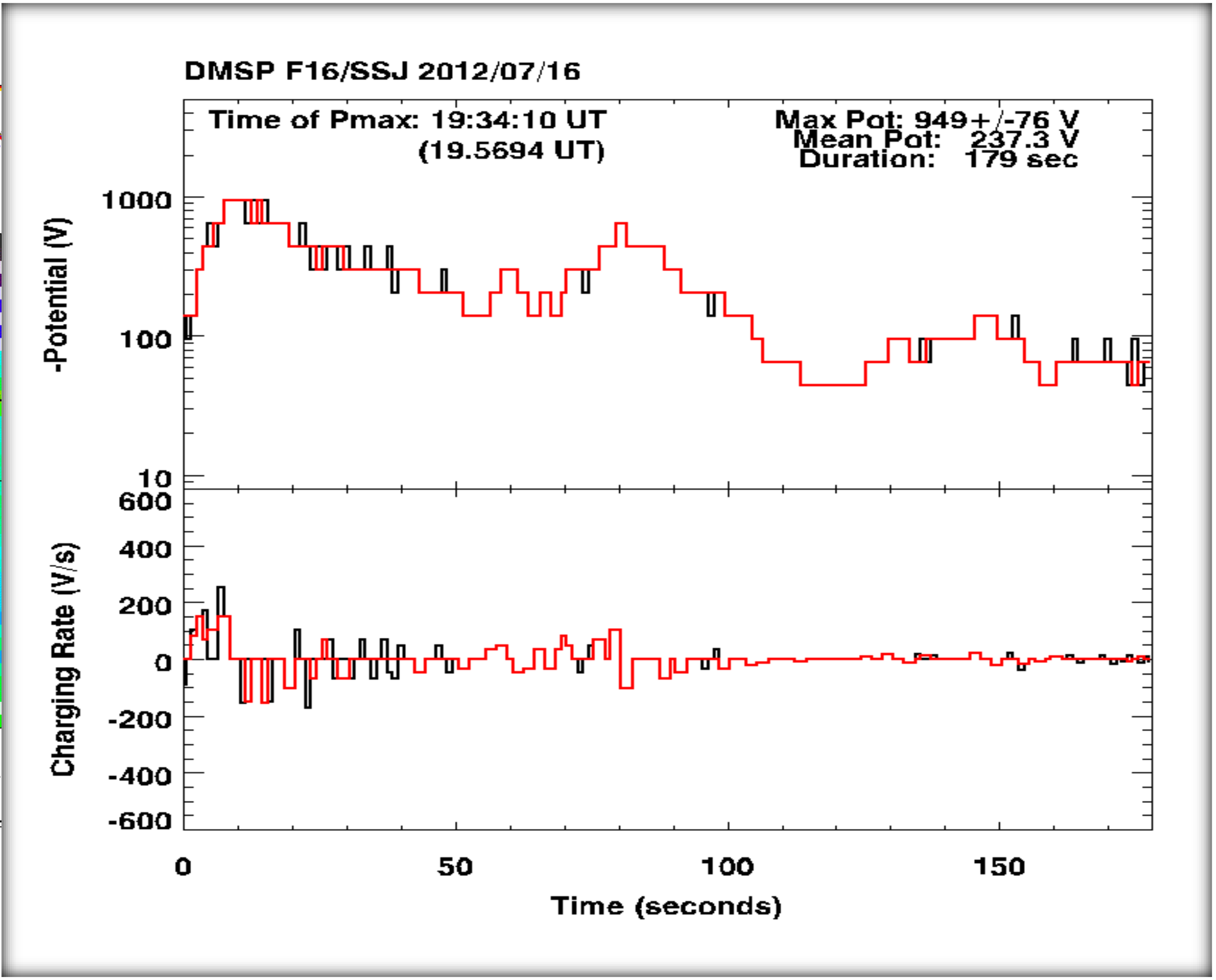
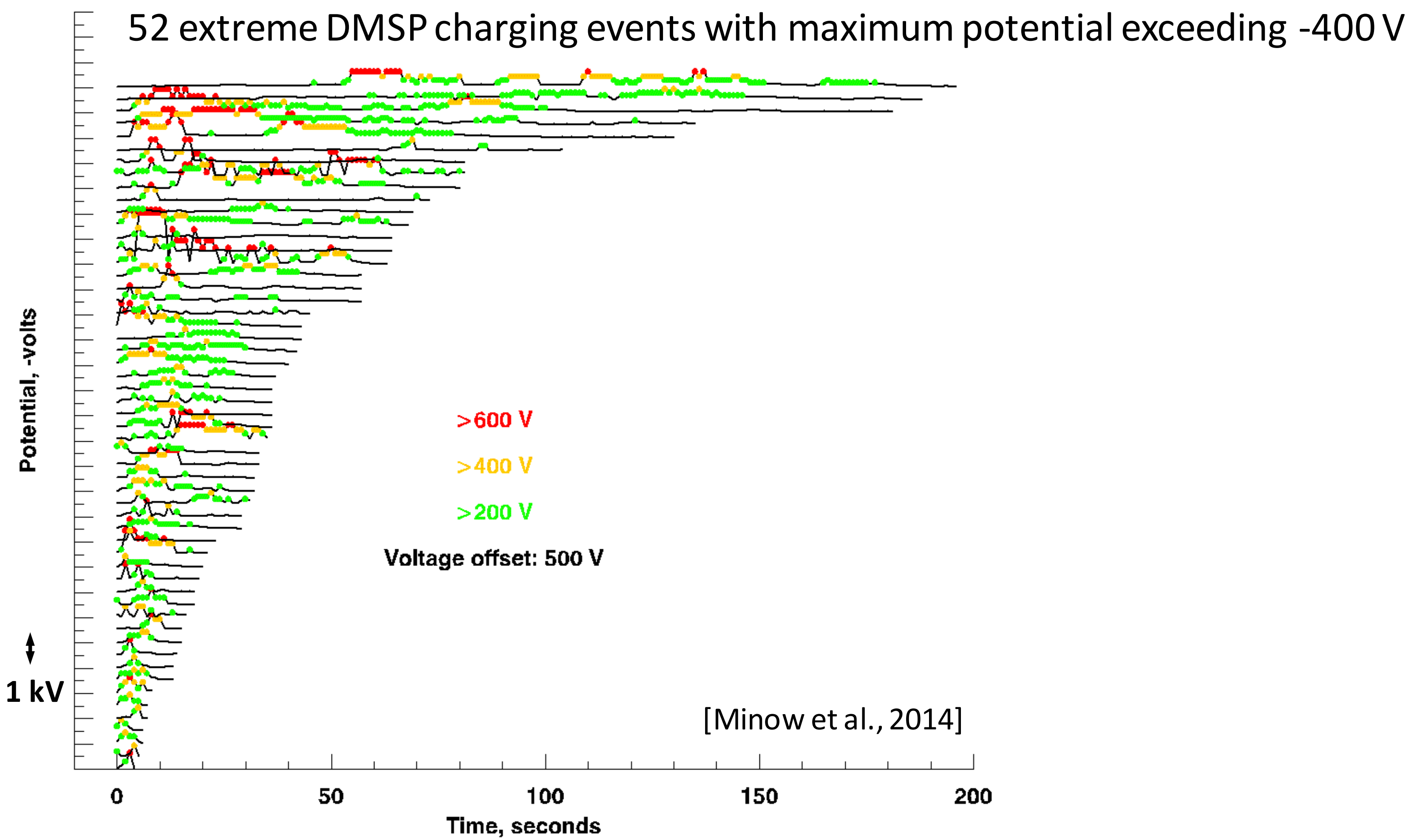


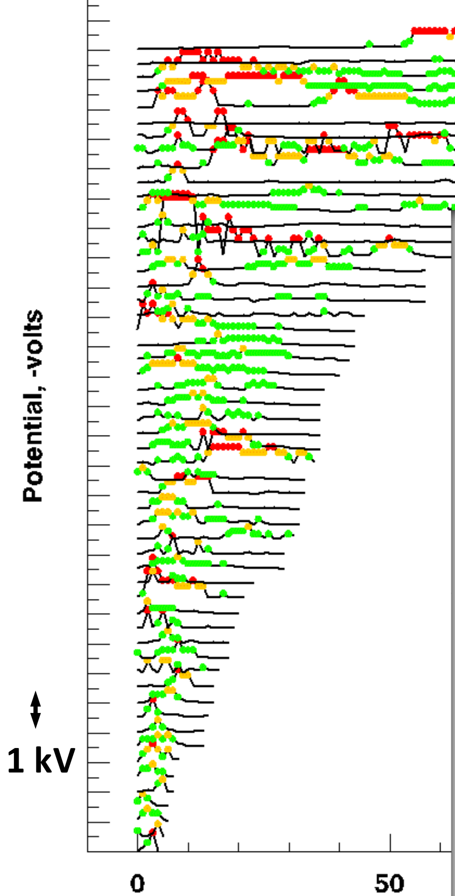


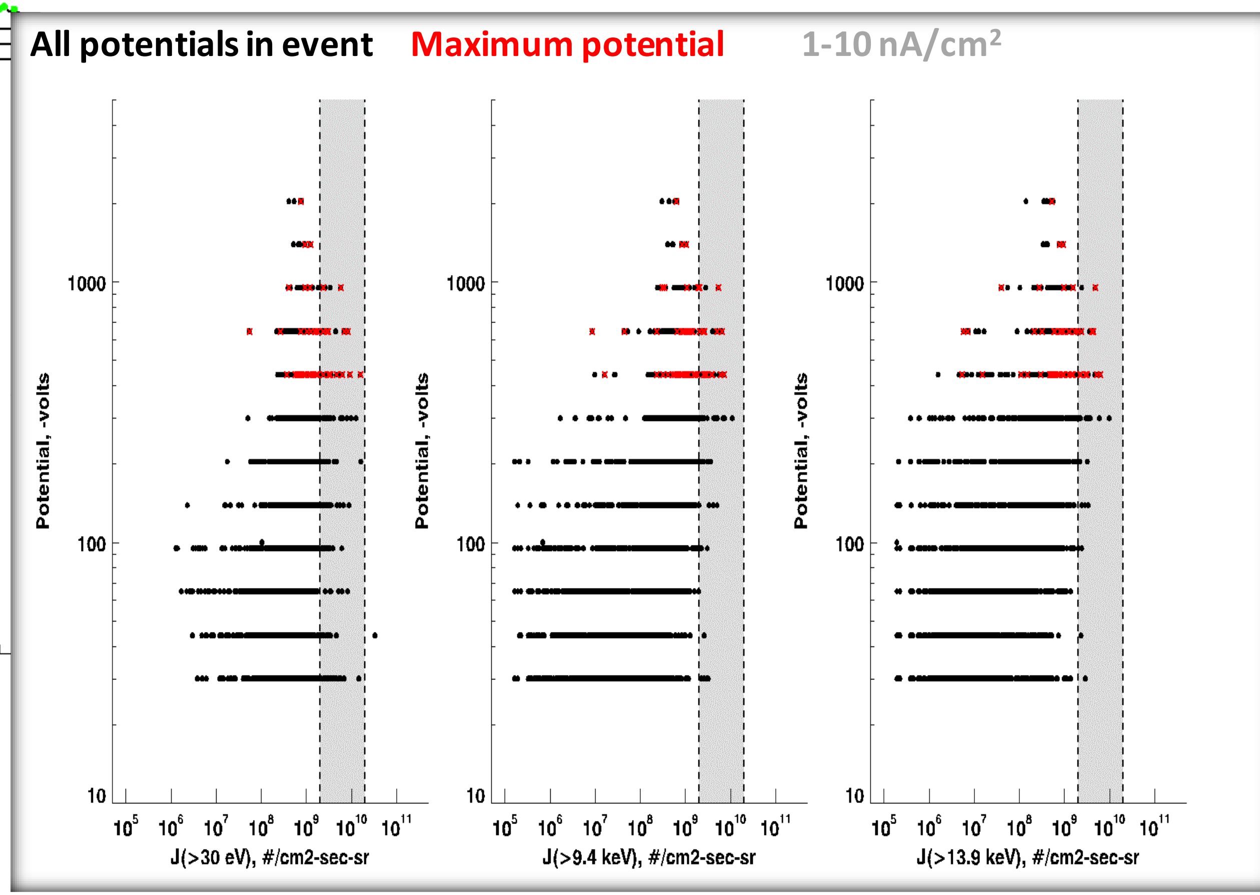
Spacecraft Potential, Charging Environment



Spacecraft Potential, Charging Environment

52 extreme DMSP charging events with maximum potential exceeding -400 V





[Minow et al., 2014

Langmuir Probe

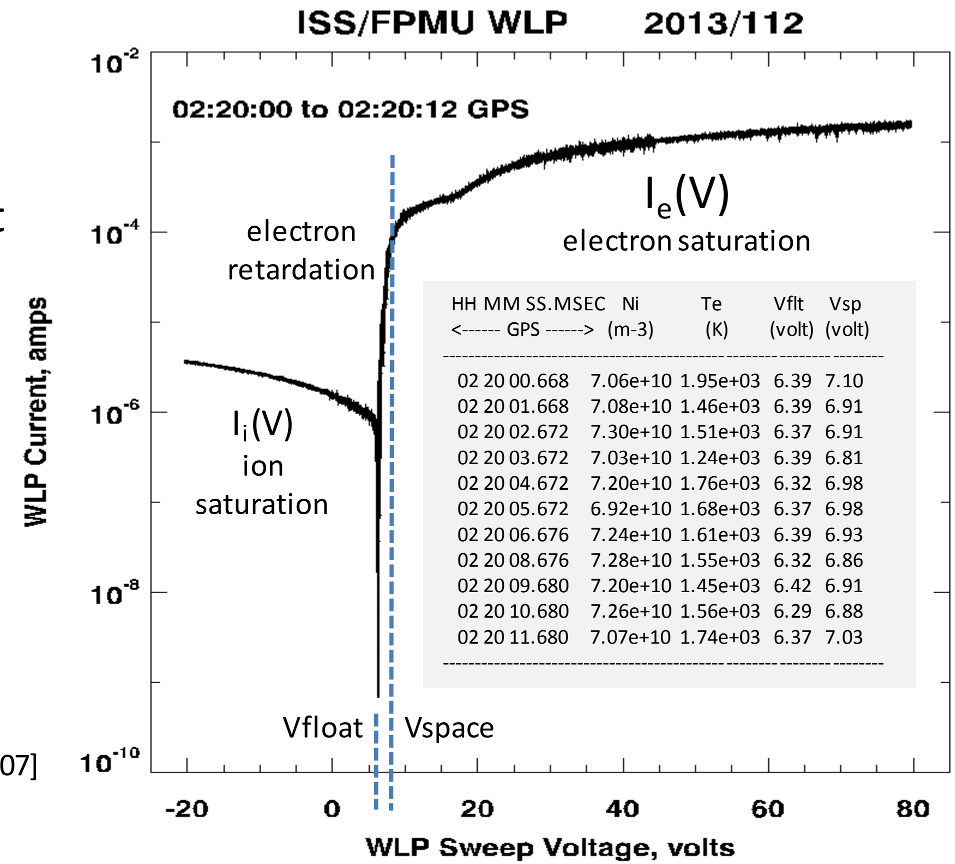
- Current probe techniques have been widely used for many years to measure spacecraft potentials
- Technique is based on measuring current collected by probe as a function of the probe voltage

$$I_i(V_B) = \begin{cases} -I_{is} exp\left[\dfrac{e(V_P - V_B)}{kT_i}\right], & V_B \geq V_P \\ -I_{is}, & V_B < V_P \end{cases}$$

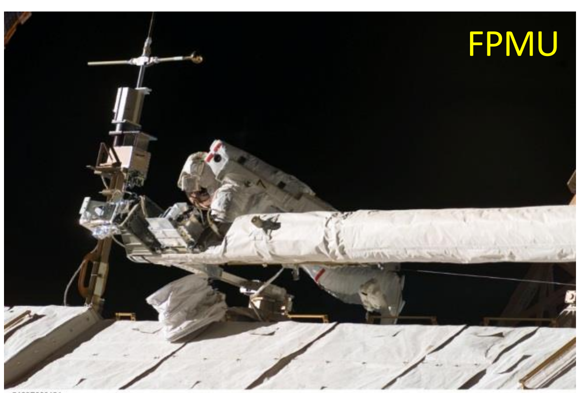
$$I_e(V_B) = \begin{cases} I_{es} exp\left[\dfrac{-e(V_P - V_B)}{kT_e}\right], & V_B \leq V_P \\ I_{es}, & V_B > V_P \end{cases}$$

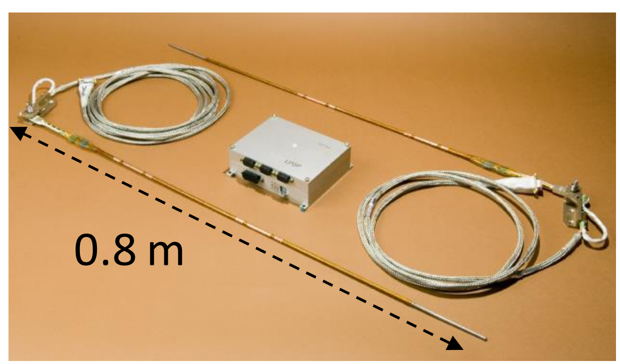
where $I_{x,s} = 0.25 e n_x v_{x,th} A_{probe}$ for x=I,e

[from *Merlino*, 2007]



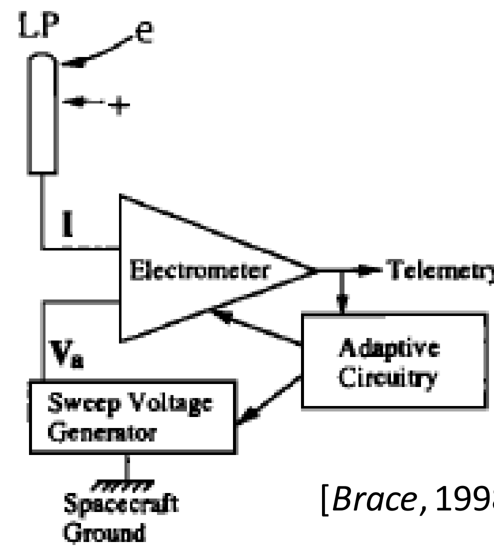
HH MM SS.MSEC <------ GPS ------>	Ni (m-3)	Te (K)	Vflt (volt)	Vsp (volt)
02 20 00.668	7.06e+10	1.95e+03	6.39	7.10
02 20 01.668	7.08e+10	1.46e+03	6.39	6.91
02 20 02.672	7.30e+10	1.51e+03	6.37	6.91
02 20 03.672	7.03e+10	1.24e+03	6.39	6.81
02 20 04.672	7.20e+10	1.76e+03	6.32	6.98
02 20 05.672	6.92e+10	1.68e+03	6.37	6.98
02 20 06.676	7.24e+10	1.61e+03	6.39	6.93
02 20 08.676	7.28e+10	1.55e+03	6.32	6.86
02 20 09.680	7.20e+10	1.45e+03	6.42	6.91
02 20 10.680	7.26e+10	1.56e+03	6.29	6.88
02 20 11.680	7.07e+10	1.74e+03	6.37	7.03





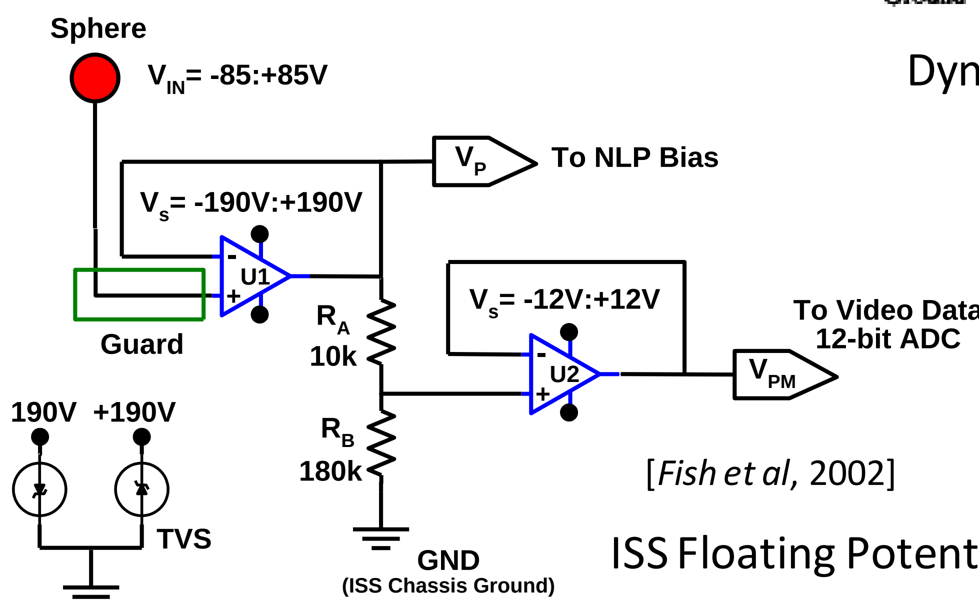
Langmuir, Floating Potential Probe

- Basic Langmuir probe circuit is based on a measurement of the current as the voltage on the probe is varied
- Fast potential measurements are obtained by monitoring a probe floating potential instead of sweeping the voltage



[*Brace*, 1998]

Dynamics Explorer



[*Fish et al*, 2002]

ISS Floating Potential Probe

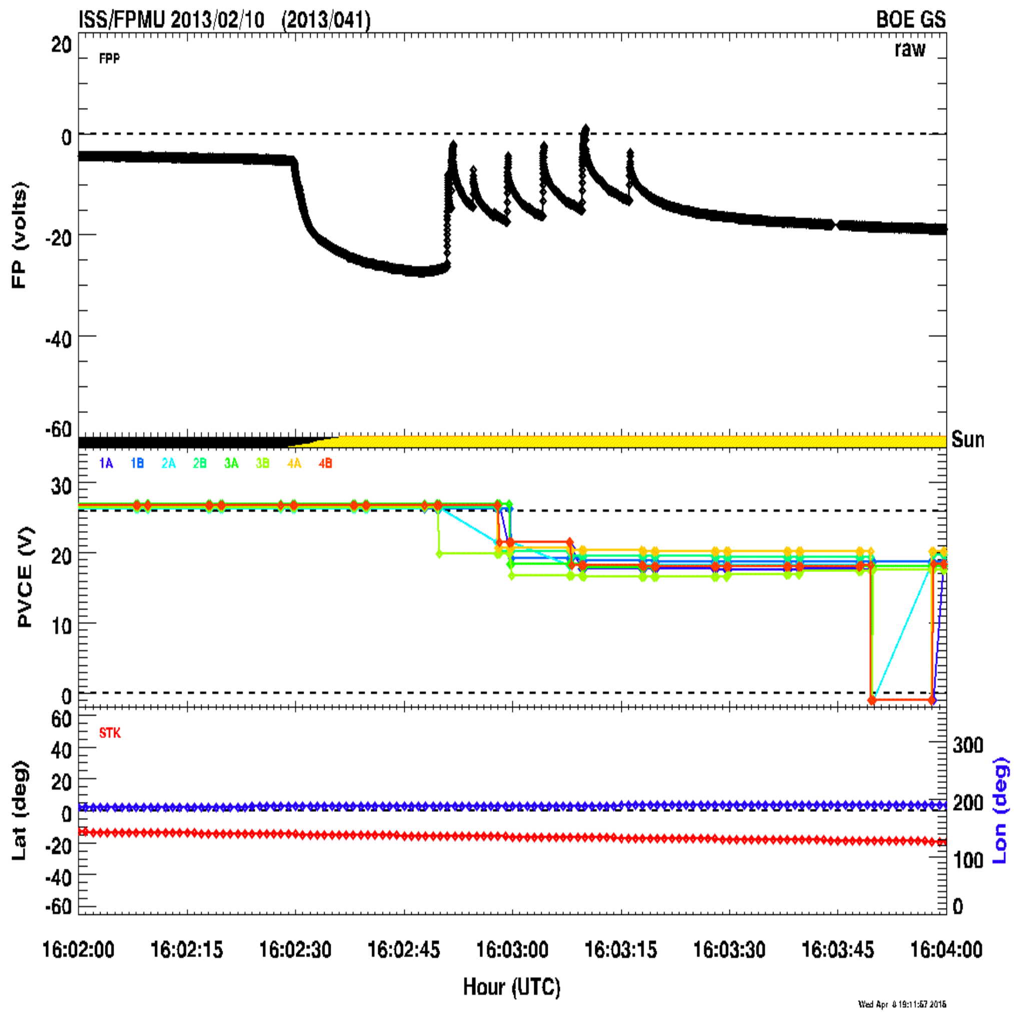
2013/041 ISS Potential Transients

- ISS Floating Potential Measurement Unit
  - Floating Potential Probe 128 Hz
  - Wide Langmuir Probe 1 Hz
  - Narrow Langmuir Probe 1Hz

- PVA shunt state demonstrates transients occur during period of active power manipulation

  PVCE (V) $\propto$ # active strings

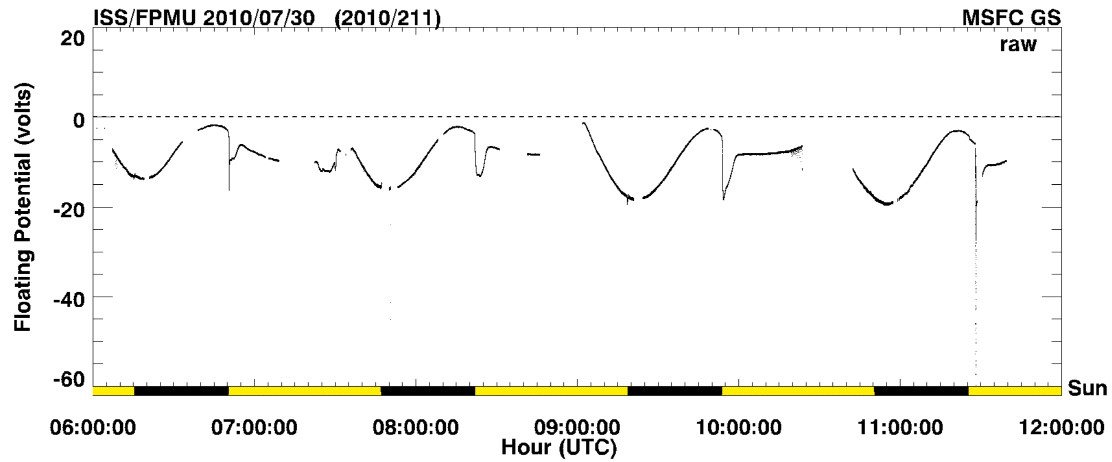
- FPP 128 Hz floating potential records show structure of transient ISS potential variations observed in post-eclipse exit environment



Time Resolution

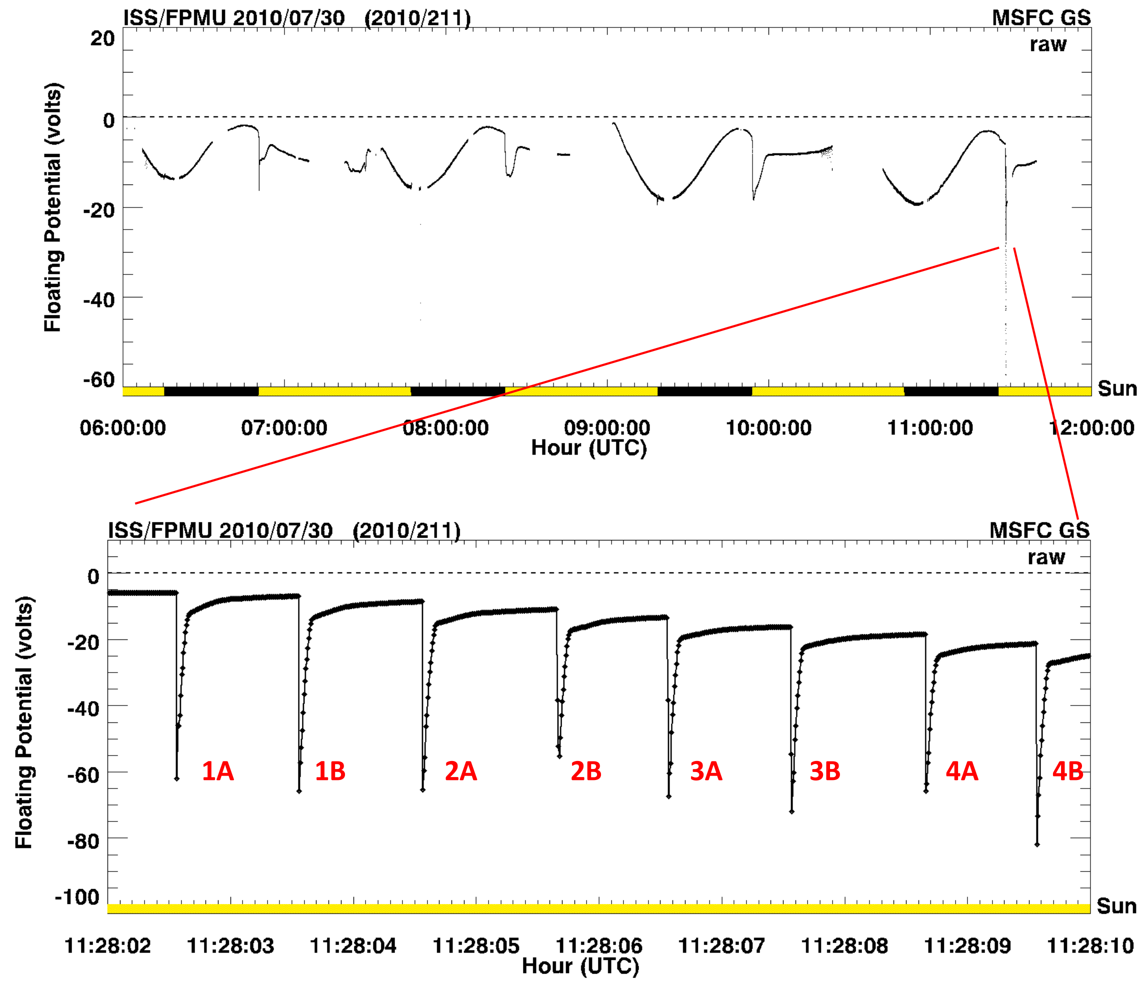
- Fast sampling of $\phi_{s/c}$ is an important capability for investigating transient potential variations due to space system hardware

- (top) Example of ISS frame potentials with contributions from inductive vxB motion and US 160 V PVA interactions with plasma environment



Time Resolution

- Fast sampling of $\phi_{s/c}$ is an important capability for investigating transient potential variations due to space system hardware
- (top) Example of ISS frame potentials with contributions from inductive vxB motion and US 160 V PVA interactions with plasma environment
- (bottom) High time resolution FPMU FPP records (128 Hz) allows examination of details of fast transient ISS potentials
- These transient ISS potentials would be missed when sampling at the lower WLP, NLP 1 Hz rates

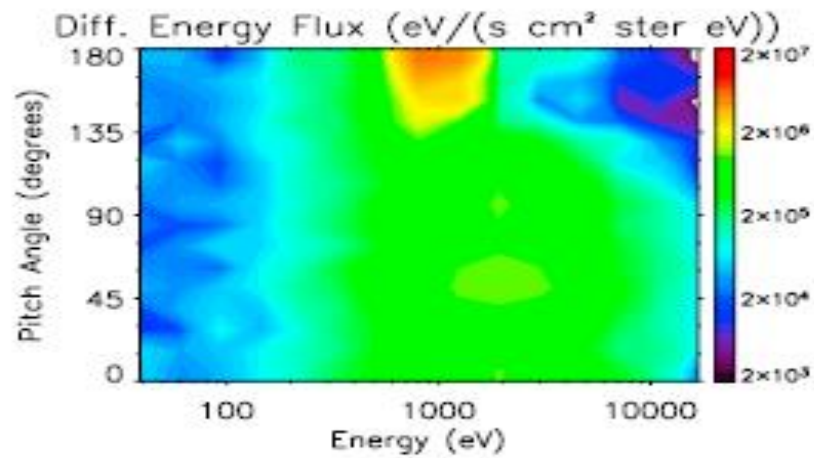


Potentials of Planetary Bodies

- Surface of planetary body will charge to some potential when directly exposed to the space plasma environment

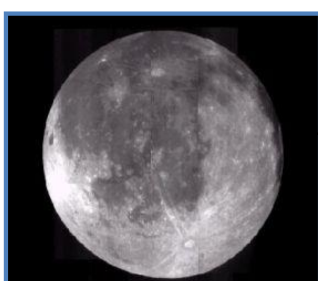
- Surface potential can be remotely inferre from measuring electron energies as a function of pitch angle from orbit above the surface [*Halekas et al.*, 2002, 2005]

$$E' = E + q\phi_{surface} - q\phi_{spacecraft}$$



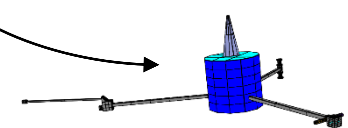
11 March 1998/15:31 UT
Moon in plasmasheet, Lunar Prospector and conjugate point on lunar surface in shadow [Halekas et al., 2005]

ϕ_{space}



ϕ_{moon}

$$E_{beam} \approx q\phi_{moon} = q(\phi_{moon} - \phi_{sc})$$



ϕ_{SC}

[from Parker and Minow, 2008]

Questions?